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Developing a Commercial Product Using a Consumer Grade 3D Printer

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DEVELOPING A COMMERCIAL PRODUCT USING A CONSUMER GRADE 3D PRINTER

by

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Abstract

Title: Developing A Commercial Product Using A Consumer Grade 3D Printer

Calvin Smith for the degree of Masters of Science in Manufacturing Engineering Technology from Minnesota State University, Mankato in April 2019

The development of affordable, quality, consumer grade 3D printers has allowed entrepreneurs to develop new products and start small businesses. As the print quality of consumer grade printers has improved entrepreneurs have been able to develop consumer quality products without the traditional expense of mass manufacturing. This change from mass manufacturing to small scale and custom production has allowed for the growth of small businesses. Websites such as www.etsy.com show hundreds of small businesses based on 3D printing, these businesses showcase thousands of products ranging from useful household items to cosplay.

This thesis covers the process of a small business developing, manufacturing, and marketing a niche product. 3D printing was utilized to develop and produce a product, along with expanding the products market requiring mass manufacturing.

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Chapter 1: Introduction

This project will detail the process to start a business based around the design, manufacture, and distribution of Pod Cases for electronic cigarettes. The project originated from a desire to explore 3D manufacturing and from observations in the use of electronic cigarettes.

1.1 Electronic Cigarettes

There is no standard name for electronic cigarettes, but there are several names that have become common in the electronic cigarette industry; vapes, vape pens, vape sticks, mods, box mods, e-cigs, e-cigarettes, tank systems, pod systems, and cigalike are the most common names used for electronic cigarettes. (CDC, 2019) For the purpose of this paper, e-cigarette will be used when discussing any electronic cigarette device unless specific models or names are required.

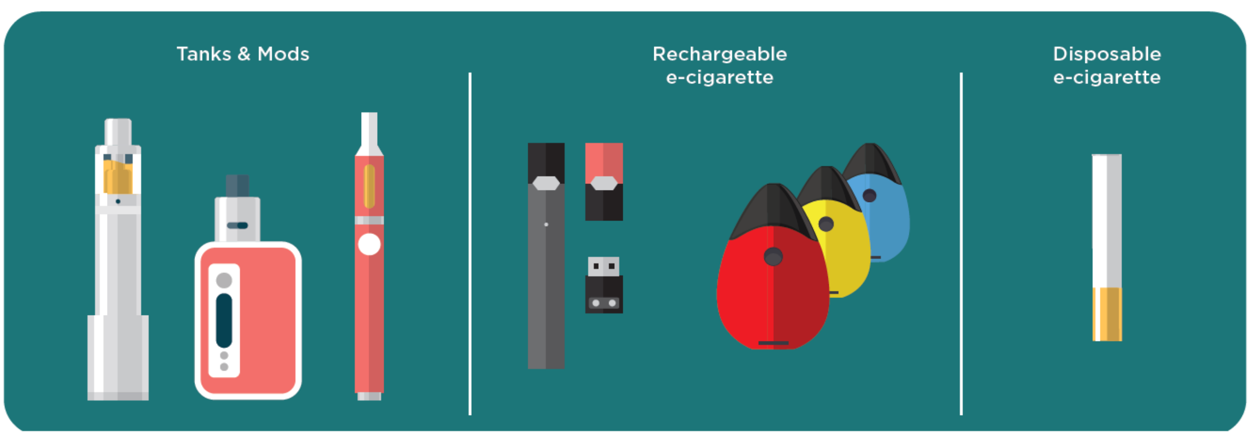


Figure 1 Standard types of e-cigarettes (CDC, 2019)

The main types of devices discussed in this paper will be rechargable e-cigarettes [Fig 1.]. These are generally simple devices with two parts: the main part of the device is a battery and circuit that accepts a pod containing the atomizer and e-juice. Two specific devices were initially studied for this project, the Mylé and the Juul.

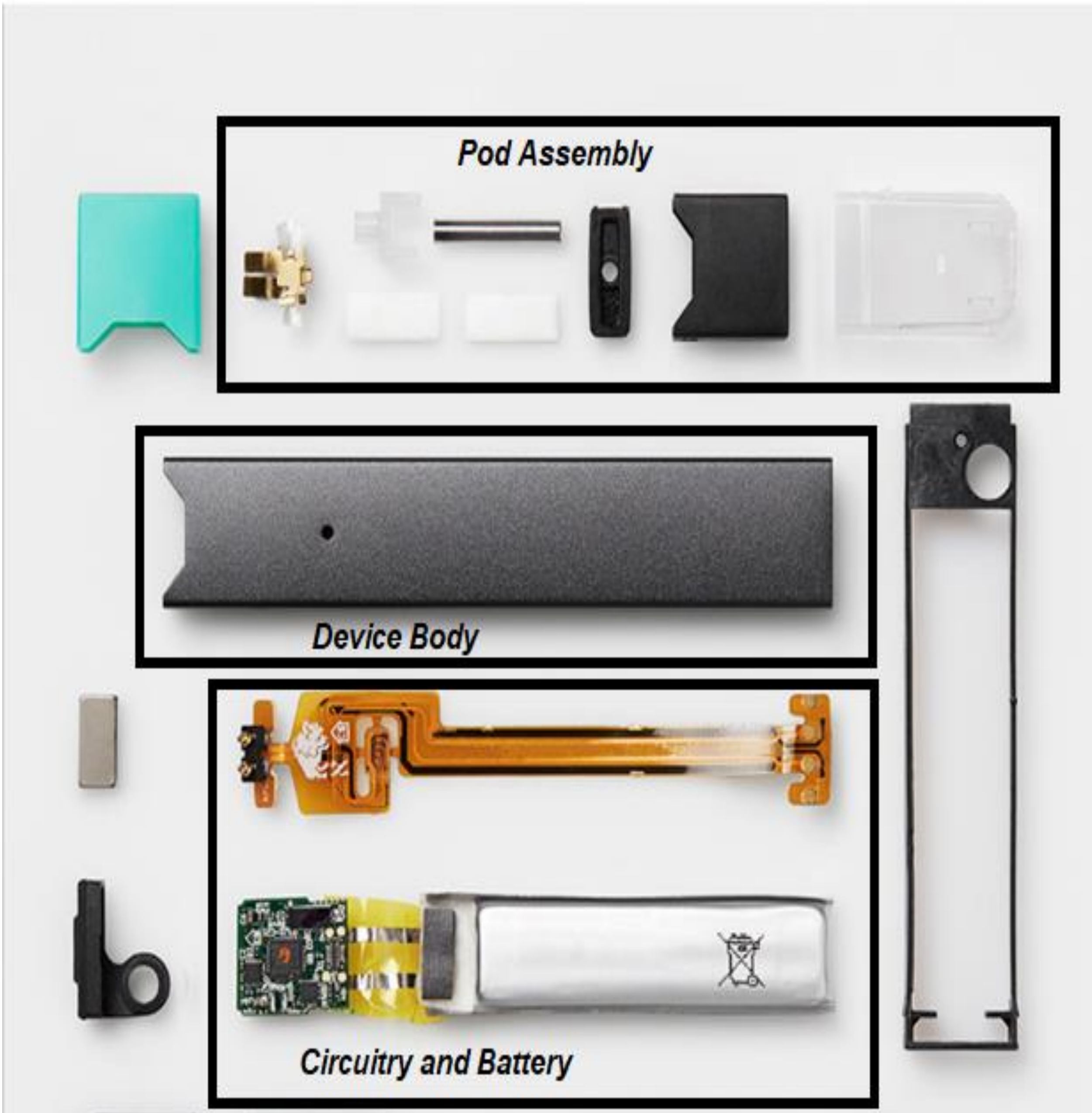


Figure 2 Myle Exploded view (Andrews Loan, 2018)

1.1a Myle

The Myle e-cigarette was chosen simply because of its immediate availability as the author was already using this e-cigarette to quit smoking traditional cigarettes. The Myle system does not have a significant portion of the market as seen by its lack of inclusion in e-cigarette market reports, however it was readily available across the United States and had a large enough market to support producing accessories such as cases on a small scale. Market support for the case was estimated at 50,000 units sold over 24 months. This estimate was made based upon the sale quantities of the Myle at local retail stores and assuming 50% of devices sold could be sold with a case. The Myle system was also new enough on the market that there were not many accessories available. Myle devices were purchased from a local vape shop for this project, however the Myle device was temporarily removed from the U.S. market in November of 2018 (Myle Vapor, 2018) for failure to comply with FDA premarket authorization. (Center for Tobacco Products, 2018) This brought a halt to further development of accessories for this product, development will continue if Myle returns to the U.S. market.

1.1b Juul

The Juul device was created by PAX Labs before Juul was formed into its own company in 2017. The Juul was first marketed in 2015 and has skyrocketed in popularity with Juul having 32.9% of the market, a larger portion than any other single device or manufacturer. (Levy, 2017)This led the author to also design and market a similar case specific to the Juul.

1.2 3D Printers

3D printers were first conceptualized in the 1980’s before being commercialized by Stratasys in 1992. There are two main types of 3D printing used by consumer grade 3D Printers; fused deposition modeling (FDM) which is the extrusion of material to build a 3D object layer by layer, and stereolithography (SLA) where photopolymer resin is hardened using an ultraviolet laser to build 3D objects layer by layer. The patents on the FDM printing process expired in 2009. (3D Printing Wiki, n.d.) As of the writing of this paper the most common form of consumer 3D printing was FDM.

1.2a Print Materials

There are several different types of materials that are commonly printed with consumer grade FDM printers. These materials all have differing properties and different printing characteristics.

PLA or polylactic acid is a cheap, biodegradable plastic that prints at a lower temperature of 205°C (Matter Hackers, 2019) and does not require a heated build plate. This plastic is the most common used among hobbyist as it has a good surface finish and prints easily with minimal warpage or shrinkage. This is a great material for basic toys and solid objects.

ABS or Acrylonitrile Butadiene Styrene is a cheap plastic that prints around 230°C with a heated build plate at 90°C. ABS is stronger then PLA and more flexible, it has a good surface finish. (Matter Hackers, 2019) Prints made from ABS can also be vapor polished using acetone to great a very smooth finish. This material is also resistant to higher temperatures than PLA. ABS is a commonly used consumer plastic with most plastic items being made from ABS.

Flexible filament is a thermoplastic elastomer that behaves much like a rubber or silicone. NinjaFlex is a common 3D printed material from NinjaTek that is a thermoplastic polyurethane, this material is commonly used for seals, gaskets, and protective applications. This plastic is very soft yet durable and has great interlayer adhesion. This plastic is printed at 210°C-250°C with a heated bed at 20°C-50°C. (Matter Hackers, 2019) NinjaFlex does require direct drive extruders and special handling during printing too keep the material from permanently bonding to build surfaces.

PETG or Polyethylene Terephthalate Glycol is a material that prints similar to PLA with the characteristic of ABS. This material is stronger then ABS however it does not suffer from warpage and shrinkage like ABS, it also does not give off strong odors like ABS when printed. PETG also has very good interlayer adhesion when printed. PETG is commonly used to manufacture water bottles. This plastic prints at a temperature of 240°C - 260°C and does not require a heated build surface. (Matter Hackers, 2019)

Nylon is one of the strongest materials commonly printed with consumer grade FDM printers, it is commonly used for functional production parts, and prototypes. Nylon can be flexible when printed thin, so it works well for living hinges. It is commonly reinforced with fibers such as glass and carbon to increase the strength of parts. Nylon does require special handling as it is hydroscopic and readily absorbed water from the air meaning it must be kept in dry storage and often must be dried further before printing. Nylon is also very abrasive to FDM printer nozzles so special hardened steel nozzles must be used, as well as specific extruder bodies as it must be printed at high temperatures. Nylon is generally printed at temperatures from 240°C to 300°C depending on the nylon alloy and requires a build surface heated to 60°C-80°C. (Matter Hackers, 2019)

1.2b Purchasing a 3D Printer

The purchase of two 3D printers by a previous employer in November of 2017 resulted in the introduction to 3D printing and the possibilities of simplified manufacturing. Research started on 2018 into consumer grade FDM 3D printers revealed that cost had fallen while quality had risen over the last decade. Months were spent researching the consumer grade 3D printers that were readily available for quality of prints, cost, reliability, manufacturer support, and software. During this time new printers were coming to market as the technology improved and changed, and the best option available at the time appeared to be the Prusa I3 MK3 from Prusa Research.

The advantages that put this printer above other printers in its class are the removable build plate, self-leveling bed, fast print speed, and materials compatibility. It has the capabilities to print in many different materials such as PLA, ABS, Flexible, Nylon, and PETG (All3DP, 2018) straight from the manufacturer and was considered by hobbyists to be the best consumer grade printer on the market. These features were only available on the Prusa I3 MK3 in this price range, other printers such as the Makerbot Replicator have self-leveling and removal bed however that machine cost $2,800 and is only capable of printing in PLA. There was also the Lulzbot TAZ6 which has a self-leveling bed that is not removable but can print in many materials, this machine cost $2,500. All of these machines are only capable of printing a single material at one time, multiple material and color printing is feasible with 3rd party modification to most printers.

The Prusa I3 MK3 (Fig. 3) was released in September of 2017 and was wildly successful. Because of its success, it had been on back order since its release date. This meant the lead time for printers was 2-5 months from the time of ordering. In June of 2018 Prusa had managed to catch up on orders and lead times were down to 2-6 weeks. On June 30, 2018 an order was placed for a Prusa I3 MK3.

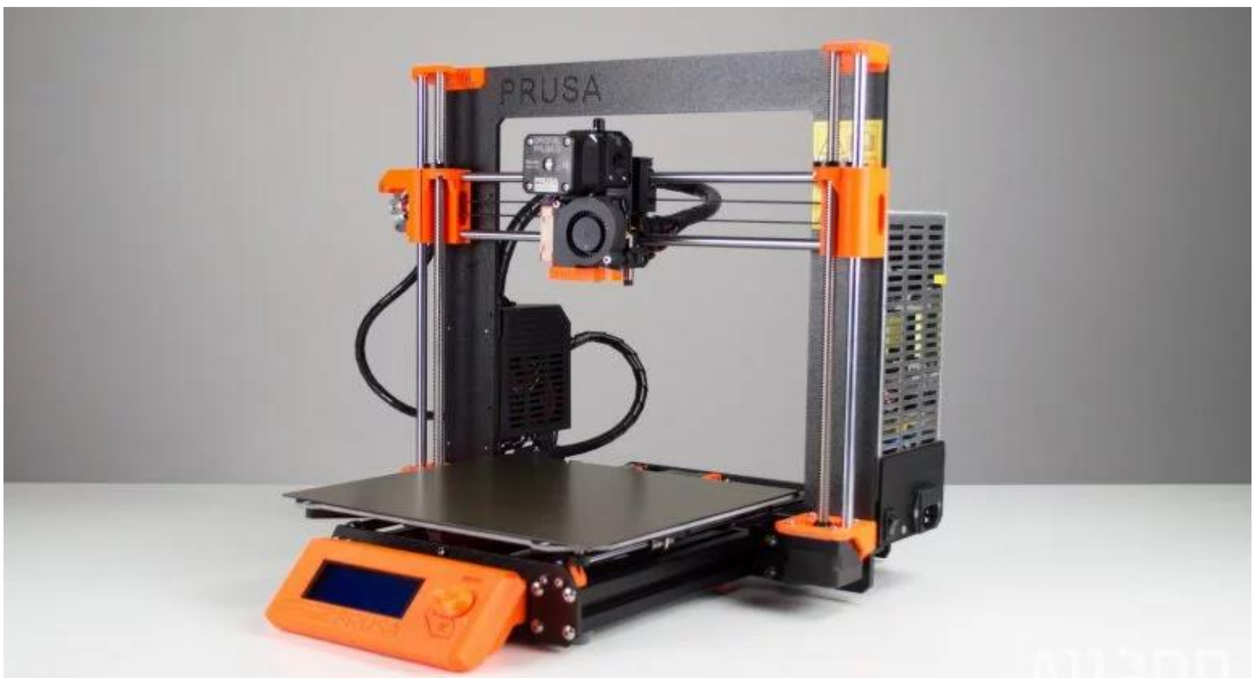


Figure 3 Prusa I3 MK3 (All3DP, 2018)

At that time the printer was available to order in two different configurations, a completely assembled and tested printer was available for a cost of $999.00 USD or an unassembled kit could be ordered for $749.00 USD. It was decided that an unassembled kit was the best option based on price and availability. The kit was received July 14, 2018 and the printer was easily assembled over the course of 5 days with clear and concise directions. The printer comes as the individual parts of the frame, axis drive components, power supply, EINSY board, LCD screen, and Extruder head. No soldiering or programing is required to build the printer; however knowledge of wiring schematics and mechanical ability greatly help the process.

Figure 4 Prusa I3 MK3 Kit

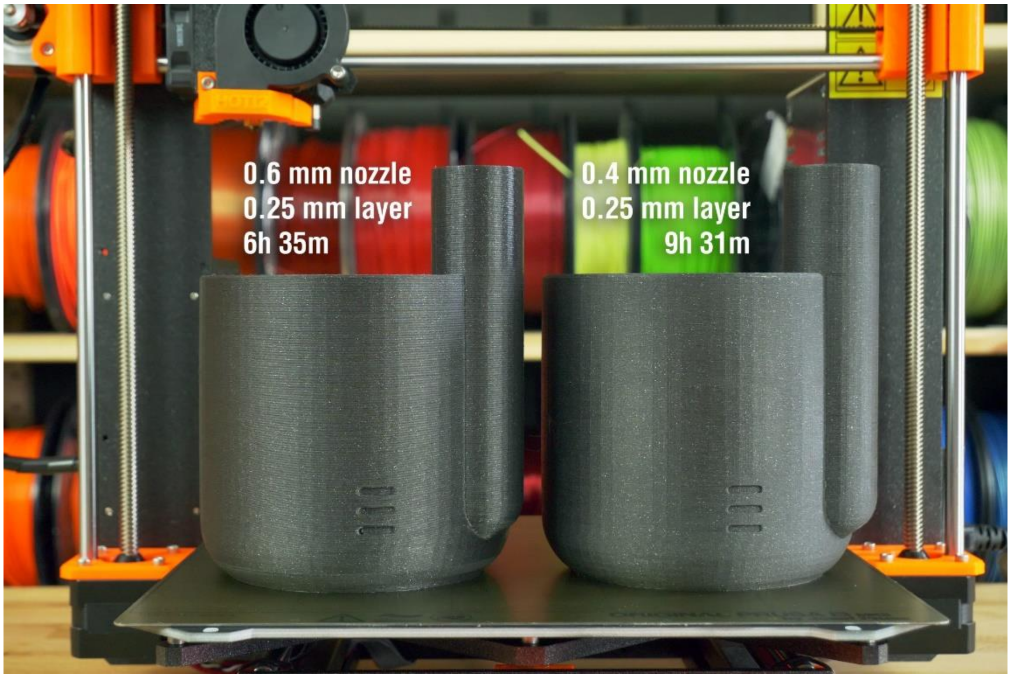
This experience allowed the author to have a greater understanding of how the printer functioned. This helps to ease trouble shooting of issues and making repairs and modifications easier in the future.

Chapter 2: Initial Idea

The initial idea for a business based around 3D printing was to offer custom printing and design through Facebook Marketplace and Facebook advertising. The goal was to offer standard items that could be individually customized such as cake toppers, game pieces, and custom ordered items from a local source. The business plan was simple with the goal being to recoup the cost of the printer and materials.

Pricing was determined by figuring the cost of materials per gram and applying that information to how much material could be printed per hour. If printing in ABS material the printer can transfer at max volumetric flow rate of 11 mm^3/sec which translates to 39.6 CC per hour. ABS plastic has a density of 1.07g/cm^3 so the printer at full capacity can print 42.4g per hour. The cost of the ABS used is $0.02 per gram resulting in a use of $0.85 of ABS per hour when printing at max flow rate. Price sheets were created using this information, cost to print objects was estimated by the amount of material used for a project.

The decision to base pricing on weight of material was guided by the cost of material being the largest cost factor in a print. Time to print an object varied greatly with nozzle size, infill percentage, and layer height but could not be faster than the max



volumetric rate of the printer, this means that two prints of the same object can take wildly different amounts of time but similar amounts of material.

Figure 5 Print Time Vs. Nozzle Size (Zuza, 2018)

The cost is shown in Table 1. These costs take in to consideration cost of material and cost to operate the printer as well as time spent altering designs and printer setup. The cost to operate the printer was calculated using a cost of $0.12 per kilowatt-hour for electricity, and operating the printer, heaters, and lights in the printer box was estimated at 1.78 kW assuming a 1500 w heater, 125w printer, 125w heat lamp, and 3w LED light strip.

Cost Breakdown Sheet		
Part	Cost	Filament Material
One Off Projects and Prototype Parts (Drawing Provided)	$0.20/gram	ABS/PLA
	$0.50/gram	Nylon
	$0.60/gram	Flexible
One Off Projects and Prototype parts (No Drawing)	$0.20/gram+ $20/hr. design time	ABS/PLA
	$0.50/gram+$20/hr. design time	Nylon
	$0.60/gram+$20/hr. design time	Flexible
Production Parts	$0.15/gram	ABS/PLA
	$0.30/gram	Nylon
	$0.45/gram	Flexible

Table 1.

The cost to operate the Printer for 1-hour printing with ABS was estimated assuming full power consumption for heaters and printer while printing at a 15g/hr average flow rate. This flow rate was the average actual flow rate of the printer during this specific print, surface finish of the object was adversely effected when printing at higher speeds and flow rates.

- $0.22/hr electricity
- $0.30/hr ABS
- Total cost to Operate $0.52/hr

An example of a prototype print made from ABS where the design was supplied,

- 190g consumed
- 7hr print time
- 30 minutes spent preparing CAD file for printing
- 5 minutes printer prep (Change material, preheat, clean build plate)
- 20 minutes removal of part and post processing.
- Cost of Electricity and Material $5.34
- Cost of Labor at $20/hr. for 55 minutes $18.33
- Total cost of part $23.67
- Charge to Customer $38

The life span of the printer was estimated at 4 years as technologies improve and change consumer grade 3D printers are outdated very quickly. Outdated printers still have usable parts that are common among all printers such as motors and have an estimated salvage value of $150 at the end of life, this gives an estimated depreciation of $187.25 per year. There are also wear items in a 3D printer such as axis screws, belts, nozzles, and feed tubes. The estimated cost to maintain this specific printer when used as a production machine running on average 16Hrs per day for 250 days per year would be $150 per year. These run times are easily accomplished on a hobby or spare time basis as the printers run with little to no input or supervision. If the prototype example above was converted to a production part of 100 units, the machine would run 14Hrs per day for 10 weeks running 5 days per week.

100 unit Production Example from prototype above

- 190g/print 19,000 grams total
- 25 spools @ $15.79/spool =$394.75 (Bulk pricing)
- 2 prints per day 5 days per week 14Hrs print time
- 10 week completion time
- Electricity cost $154
- Total cost of production $548.75
- Charge to customer $2,850

The production sample above was also quoted through a commercial 3D printing service for $7,500. The commercial quote was for a Nylon material which raised the cost however when converted to Nylon and applied through the above price sheet it could be quoted at $5,700.

At the time of writing this paper this business plan is still in use with several one-off prints having been completed for customers as well as prototypes with production quotes for other companies.

Chapter 3: Design Protection

There was concern over protecting the design of the cases so that others could not simply copy the case and profit from it. A local attorney gave input for what could be considered for a patent as well as contacts of patent attorneys. It was discovered that filing a patent is a very time-consuming process with many hurdles and patent attorneys charge $500 per hour and it was expected to have a minimum of 10 hours just in filing a patent.

There were two types of patents researched for protection of the Pod Case design, the first was a utility patent. This is the standard patent used to protect an original product, machine, process, or system this patent protects the functionality of a design. The second type of patent that was researched was a design patent, this patent can be used to protect the ornamental design of a product such as the shape of a bottle or shoe. The correct form of patent for the Pod Case was decided to be utility patent as that would protect the functionality of the case and allow for a provisional patent application to be filed.

While research was conducted on the patent application, life span and earning potential of the product a temporary provisional patent was filed so the design would have an official time line attached to it. This patent-pending status is easy to file and has a filing fee of $147, patent-pending status is considered active for 1 year from the date the application is filed and can be converted to a complete patent any time during that 1 year. The patent-pending status does not give any protection to the design however it does give an earlier filing date. This was important as the US has a first to file standard for patents, where if multiple patents for the same thing are received the first to file will get the patent even if other designs were built first. The speed of the vapor industry and production size of our product did not make financial sense to complete the patent process. Success of the cases could be measured when other companies copied the design and priced the original out of the market.

Chapter 4: Design Flow

4.1 Initial Design

The Pod Case was designed to solve the problem of carrying loose e-cigarette pods (Fig. 6) in a person's pocket where they could be lost or broken when rubbing against other items in the user’s pocket. When speaking with Myle users it was normal

Figure 6 Myle PODS (My Vape Store, n.d.)

to hear of piles of pod blister packs with one or two pods left in them in vehicles or of running out of pods during the day with no extras on hand. A person that would smoke one or more packs of traditional cigarettes per day would easily consume more than one pod per day using the Myle. The first case was designed to be a custom product to solve these issues.

The first Pod Case was designed specifically for 3D printing with very little constraints for manufacturability. It was designed around the Myle and had specific design parameters. The case had to be capable of holding the e-cigarette without the case easily slipping off yet be able to remove the device, this was tested by holding the case lightly by the sides and shaking the device while upside down. The battery indicator lights had to be visible, so the devices state of charge could be seen while it was in the case, and it had to hold at least one extra pod. The goal for the size of the case with device and pods was to be 50% smaller then a pack of traditional cigarettes which measures 3.5” tall by 2.125” wide and 0.875” thick.

4.2 Design V1.0

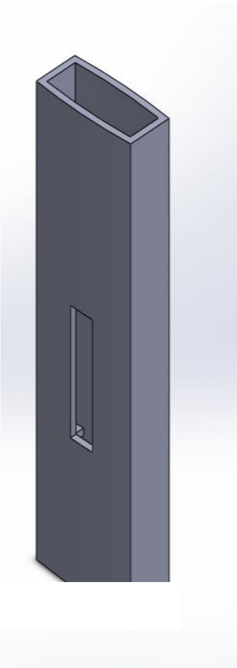


Figure 7 V1.0

The very first printed design (Fig. 7) met all the initial design criteria, it held one extra pod under the Myle device, allowed the user to see the battery indicator and only made the device slightly longer so it easily fit in a pocket. This design worked as intended however it did have some problems. The case did not allow the user to charge the Myle as the micro USB charge port is located on the bottom of the device so the user had to remove the device from the case to charge. The case also made it difficult to remove the extra pod from the bottom as there was no good way to grip the pod. This case was printed using PLA (Polylactic Acid) plastic which is the standard 3d printing plastic because it is renewable, biodegradable, cheap, has minimal warping, easy to print, and high strength. The downfalls to printing with PLA is it is brittle, and due to its glass transition temperature or temperature when the material becomes soft enough to flow, it does not hold shape in hot environments. The print used the basic Prusa MK3 settings for PLA at 0.15-layer height using the standard 0.4mm nozzle. This case took 45 minutes to print and consumed an estimated 6.8 grams of PLA with a material cost of $0.17 per case.

4.3 Design V2.1

Figure 8 Design V2.1

The second design that was printed moved the extra pods in line next to the device, this design allows the user to carry two extra pods, charge the device without removal from the case and had the added benefit of allowing the device to rest vertically on its bottom. This case was printed using ABS (Acrylonitrile Butadiene Styrene) which is a very common 3d printing material. ABS is stronger than PLA, less brittle, and still cheap. It has the added benefit that ABS can be vapor polished using acetone, this smooths the part giving it a better visual appearance and makes it stronger by increasing the layer adhesion.

ABS is more difficult to print as it tends to warp when printed and must be printed at much higher temperatures than PLA. When printing in ABS it is suggested to keep the printer in an enclosure to maintain an environmental temperature of 35℃-50℃ and to keep any air movement away from the printer. This allows the ABS to cool slower and keeps it from warping. This was

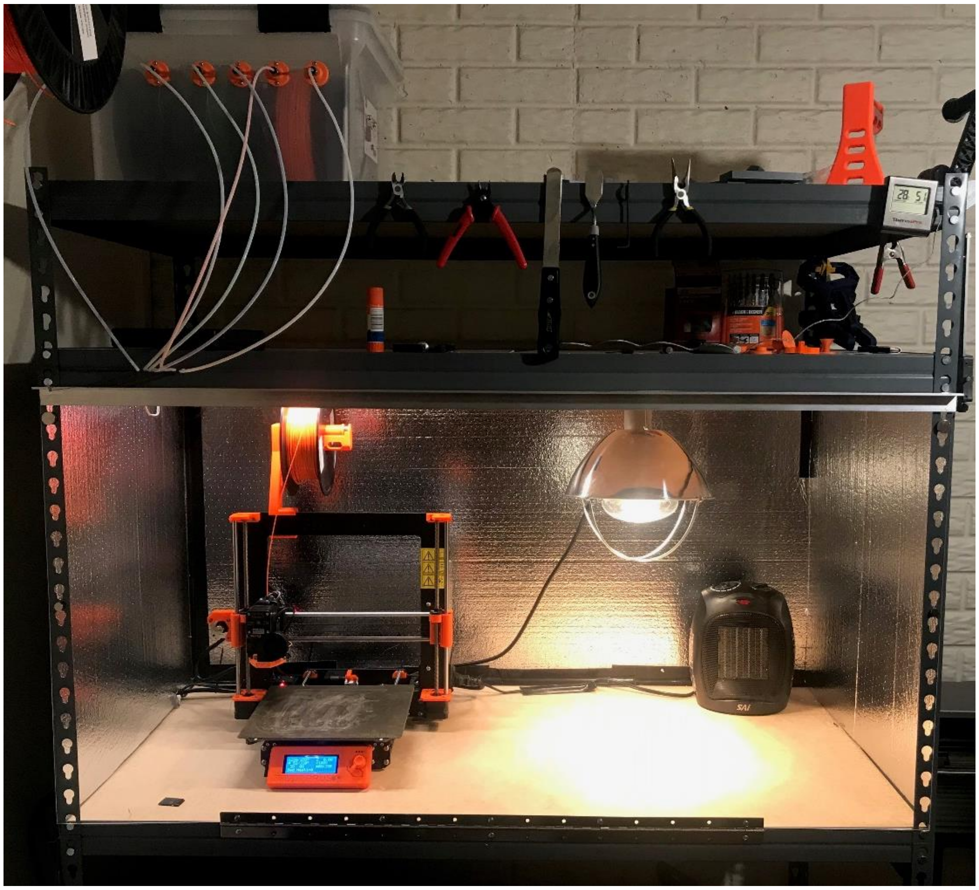


Figure 9 Printer in Enclosure with Dry Filament Box

accomplished by moving the printer onto a shelving unit which was insulated using foil backed polystyrene foam with a clear polycarbonate door. A 125W heat lamp was added to maintain the enclosure temperature at 45℃ during printing and a 1500W space heater was added to initially heat the enclosure. (Fig. 9) This design was printed in 160 minutes using the standard Prusa i3 Mk3 ABS settings at 0.15mm layer height using a 0.4mm nozzle. The printer consumed an `estimated 8.4 grams of ABS which cost an estimated $0.17 per case.

During testing of this design, it was discovered that ABS tends to shrink by 1% over 30 days. This led to the cases becoming permanently attached to the devices inserted into them. The cases would shrink enough that they would crack around the corners. (Fig.10)

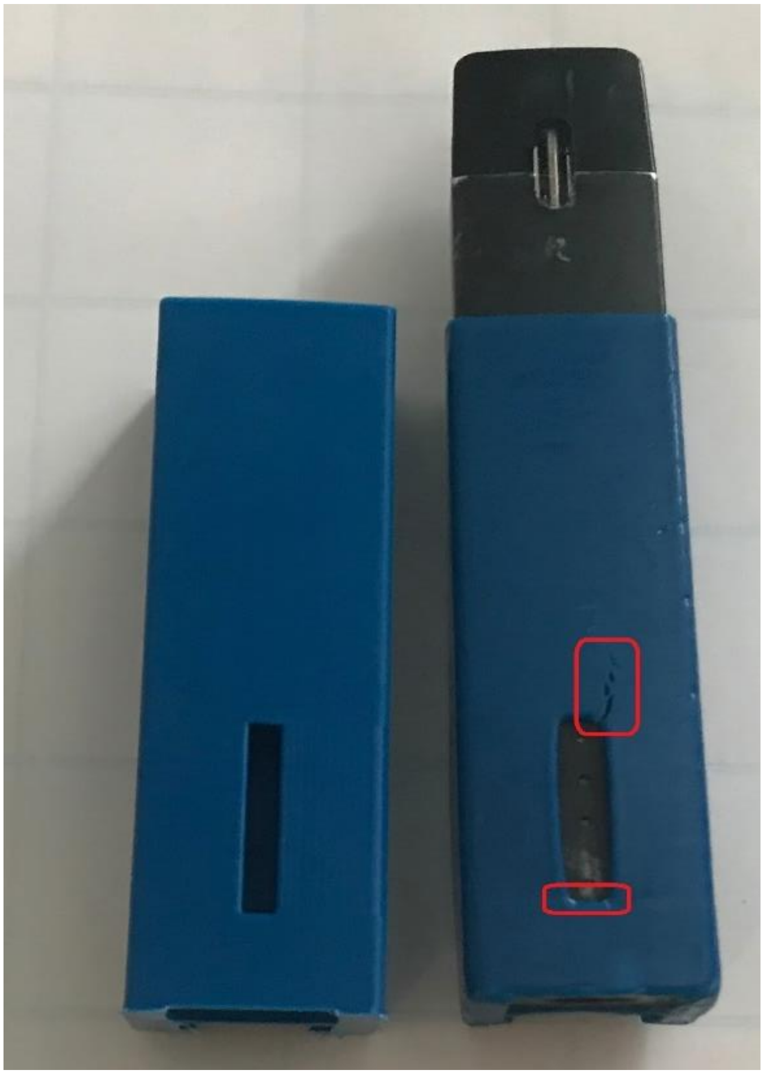


Figure 10 V2.2 New VS OLD

4.5 Design V2.3

This design iteration came out of the first marketing meeting with a local vape shop. The main factors that were changed in this design was the overall size of the case was slightly increased by 1% to better fit the devices and changing the material to Ninjaflex. This material is a TPU (thermoplastic polyurethane), it is very soft and

Figure 11 V2.3

stretches easily. This material will not scratch a device and allows the case to stretch to fit slight variances in the devices. This design took 180 minutes to print using the standard Prusa i3 Mk3 flex settings at a .2mm layer height using a 0.4mm nozzle. The printer consumed an estimated 12.5 grams of Ninjaflex per case at a cost of $1.37 per case.

4.6 Design V2.4

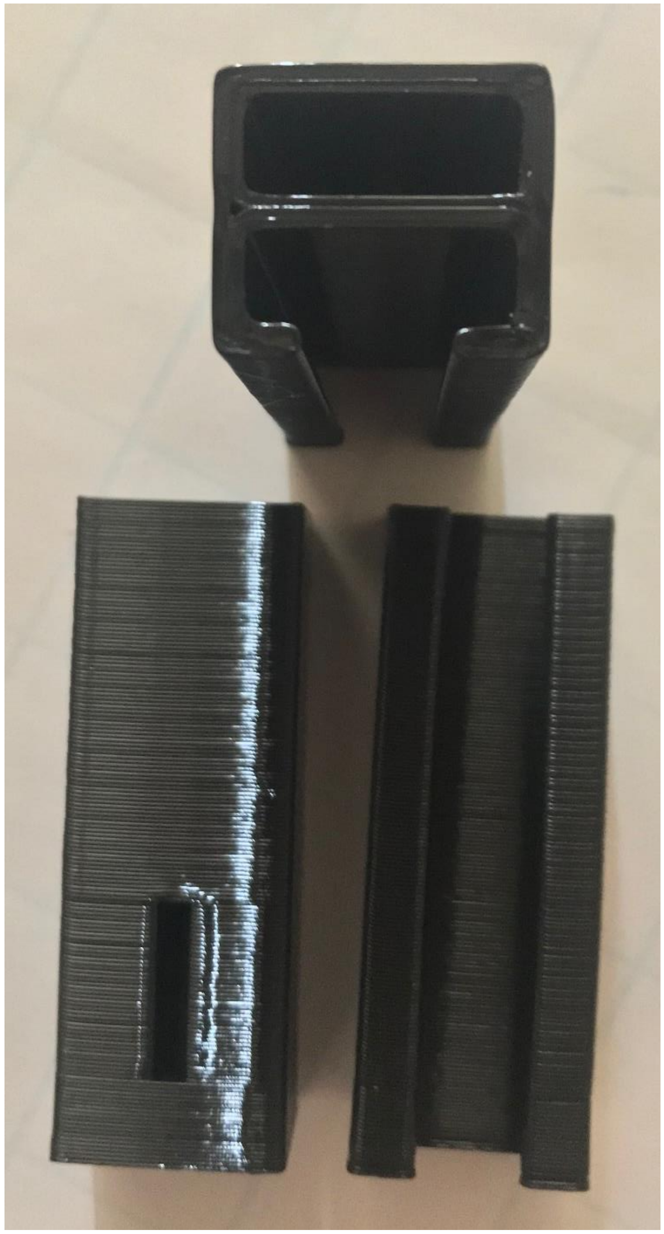


Figure 12 V2.4

This is the final design for 3D printing, and is the last iteration based off the V2 design. This case had slight modifications to the design, the back of the case was opened up to allow easier access to extra pods. The open back allowed the used to simply slide their finger across the pods to remove them. The solid bottom was also removed to allow pods to be accessed from either end of the case, this also gave the benefit of decreasing overall print time and material used per case. The removal of the back and bottom of the case required the case walls to made thicker. The wall thickness was changed from 1.5mm to 2.0mm this gave the case more rigidity and structure. The overall height of the case was set a 65mm as this was the height of two pods stacked together and prevented interference between the case and users mouth when using the Myle device. Case V2.4 also brought changes to the 3D printing process. The printer's nozzle was changed from 0.4mm to 0.6mm this allowed for larger layer heights as well as more material flow through the printer. Layer height was increased from 0.2mm to 0.45mm. Print head speed did have to be slowed by 5% and print temperature was also increase by 5%, these changes were to compensate for the larger amount of material flow through the print head. These changes allowed a single case to be printed in 52 min while consuming 11grams of Ninjaflex at a cost of $1.22 per case. The cases must be printed one at a time to obtain the best surface finish and to minimize material stringing. This design and process allows for the production of up to 12 cases per day, with a single printer and operator taking into account for other work, errors, and miss prints 50 cases per week can easily be printed.

4.7 Design V3.2

Figure 13 V3.2

This design came out after the second market meeting, it was a design that had been reworked for manufacturability and could be made via 3D printing or injection molding. Engineers from Protolabs assisted in this redesign, (Fig. 13) it had draft added to the internal surfaces as well as simple tabs to hold the device in the case. (Fig. 14) The thickness of the case walls was modified to allow for plastic flow in the mold. This was the first case to have production samples made in China.

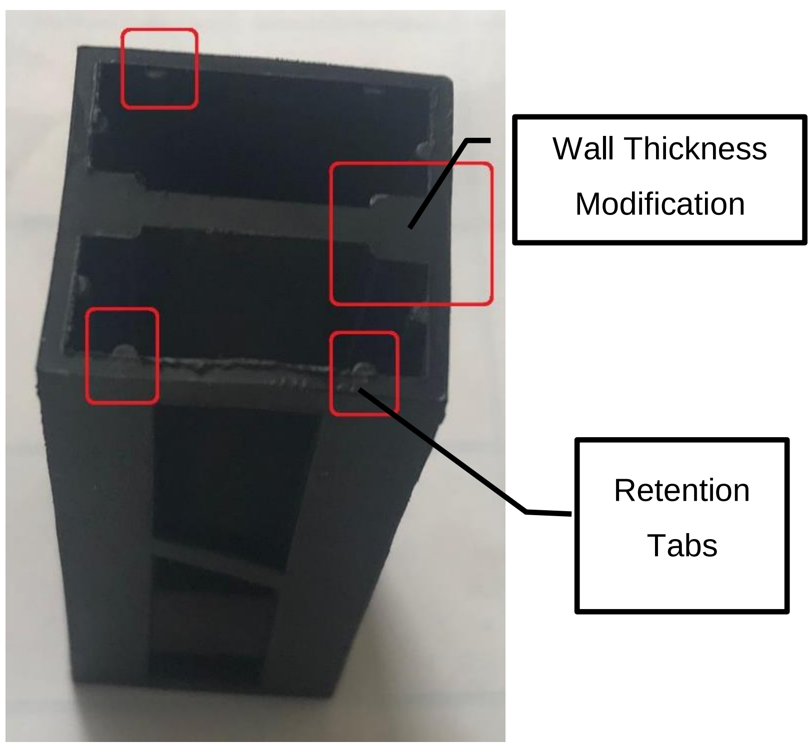


Figure 14 V3.2 modifications

Chapter 5: Marketing

5.1 First Market Attempt

Design 2 was the first case where a market potential was realized, this design was taken to a local vape shop too see if there was interest in the case. This led to meeting with the store owners, purchasers and a few other employees to evaluate the design. The design was very well received and supported, there were several questions about production quality and quantity. There was concern over how clean 3D prints could be made, mainly would print lines and seams be visible and was there away to remove any material stringing from the production cases. At this point only 8 cases could be printed in 24 hours due to limitations from the size of the printer, this concerned the shop as they had 10 locations and wanted to be able to order in large quantities. There was discussion about having the cases mass produced via injection molding, leading to further research on this possibility. There was also concern over the material of the case as the ABS was hard enough it could scratch the devices as well as the ABS had shrunk slightly from the time of manufacturing and were difficult to remove from the devices. It was also discovered at this meeting that the different colors of Myle devices had slightly different sizes, namely that the blue and red devices were up to 0.015in thinner than the black and gray devices. The results of this meeting were that subsequent designs and material testing would be required, and mass production would need to be researched.

5.2 Second Market Meeting

The second meeting with the local vape shop was to present V2.2, this design remedied the problems of device fitment as well as concerns over damaging the devices with the case. There was greater concern with this case over quality as the printing process with Ninjaflex can leave strings on the cases and make them look unfinished. It was also discussed that they would only be interested in black cases as this is a neutral color that works well with all the devices and is not a personal color. There was still concern as well over production quantity, only 8 cases could still be produced in 1 day, so quantities would be limited to under 40 cases per week. This would be acceptable if only the local shop carried the product however the desire was to market the cases nationally through a distributor which required fulfilling orders in the thousands of units.

Figure 15 Packaging

There was discussion at this meeting about pricing of the Pod Case, it was generally agreed that the market price of the case would be between $9.99-$11.99 per case to the consumer. This price left room for any variations in packaging, shipping, and manufacturing it also left enough markup for the company to consider wholesale of the Pod Case.

Discussions were also started about product packaging, cost to wholesale, and changing manufacturing to injection molding. Packaging for final consumer could be accomplished by packing cases into a clear display bag with a business card sized insert for product information and marketing. (Figure 15) The estimated increase to product cost was $0.10 per case based on materials for packaging. The local vape shop owners also owned a distribution company that distributed to other vape shops all around the country, their estimation of the market was that a total of 50,000 units over a 24-month period could be supported with the correct marketing.

Chapter 6: Injection Molding

After the second marketing meeting research was started into mass production of cases via injection molding. The first steps were to find a company that would be willing to design the mold and do minimum production runs of 2500 units with a projected total of 50000 units over 24 months. There was a desire to keep manufacturing local, so U.S. based manufacturing was first researched. This was when Protolabs INC. was contacted. They specialize in small production manufacturing and rapid prototyping; the version 2.2 case was sent to their engineers for manufacturability assessment. This design did not pass their assessment and required modification for injection molding.

The V2.2 case did not have any draft on interior or exterior surfaces to accommodate removal from a mold, there was also concern that the sidewalls would be too thin to facilitate correct material flow in the mold. V3.1 was the redesign that was quoted for production from Protolabs. It was estimated that it would take 15 days to manufacture the mold and start producing parts. The cost to have the mold manufactured was $7500 and had a cost of $1.22 per unit with a 5000-unit order. This quote gave an estimated cost of $1.51 per unit for 50,000 units when ordered 5000 units at a time, this total cost included shipping and packaging. At this time it was decided to also get a quote for production from Leads Engineering based out of Shenzhen, China, the same design was used as it was already a known good design for injection molding, the quote from Leads Engineering was 30 days to produce the mold at a cost of $4900 and orders of 2500-5000 units were $0.75 per unit with a lead time of 1 week. There would also be significant shipping cost as well as import tariffs if this production route was chosen. Further research was done to find that a shipment of 5000 units via air would cost an estimated $1,500, and the import tariff would also cost another estimated $206.25. The tariff cost was found by classifying our case under the Harmonized Tariff Schedule, our classification was HTSUS 3926.90.9990 dutiable at 5.4% of the value of the cases being shipped. The value of the cases was determined by the cost of production of the cases as that was the defined value. Once shipping and packaging are all added the cost of 50,000 units delivered in 5,000-unit increments was $1.21 per unit. This is a 20% reduction in cost over the expected life of the product.

Chapter 7: Conclusion

7.1 Continued Development

Version 2.4 of the Pod Case was the final developmental stage for 3D printing of the Pod Case, this design was approved by the stores interested in carrying the case and the distributer who was interested in the case for wholesale. The cost to produce a Pod Case via 3D printing is estimated at $3.00. The cost to retail outlets of the finished case with packaging was $5.00 per unit with the capacity to deliver 50 units per week and a retail sale price of $10.00. This price point and production capacity makes the case too expensive for wholesale distributers, however there is still research being done to make V2.4 via injection molding and estimates at time of writing this thesis show cases could be manufactured, packaged, and delivered for $1.25 per unit with a wholesale cost of $3.00 per unit. There must be a market to sell 5000 units minimum to continue research into mass production via injection molding.

The type of production of the Pod Case will be decided by market size. It is easily produced by either 3D printing or injection molding with the main factor being how many units can be sold. The break even point for this design is 5000 units, if only 5000 units need to be made 3D printing would be the most practical and profitable for this business model. This number of units could easily be made over 1 year with the addition of 2 printers to the business model and would still be profitable. If there is a market larger then 5000 units injection molding becomes more practical and profitable as larger quantities can be produced at a much higher rate of 10,000 units per week. This larger quantity also brings the overall cost of the cases down which allows for an acceptable profit margin for distributers and retail outlets.

7.2 Conclusion

As of the writing of this theses the Myle case had still not made it to market. The temporary removal of the Myle device from the U.S. market slowed development as commercial sales of the product were difficult. Wholesale markets were leery of purchasing accessories for a device with an unknown market availability. There is still opportunity to sell the cases to local venders as supply of the Myle is still available. The reduction in market size to local venders only has brought the manufacturing of the cases back to a scale supportable by 3D printing and has made the cost of injection molding prohibitive.

The possibility to earn extra income from 3D printing is very realistic with minimal labor involved. Overall there was strong profit margin in small scale manufacturing and prototyping as the labor involved only includes basic setup and design time while the printer can run unsupervised for the majority of time involved.

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Appendix

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Preparation date: 09-06-2016 Version No.: 2.0

Technical Data Sheet

ABS by Innofil3D BV

Filament suitable for all commercially available leading brands 3D FDM/FFF printers

IDENTIFICATION OF THE MATERIAL	
Trade name	Innofil3D ABS
Chemical name	Acrylonitrile Butadiene Styrene
Chemical family	Thermoplastic Copolymers
Use	3D-Printing
Origin	Innofil3D BV

GUIDELINE FOR PRINT SETTINGS	
Nozzle temperature	240 ± 10 °C
Bed temperature	80 – 100 °C
Bed modification	Tape
Active cooling fan	No/Yes (up to 25%)
Layer height	0.08 – 0.2 mm
Shell thickness	0.4 – 0.8 mm
Print speed	40 – 80 mm/s

Settings are based on a 0.4 mm nozzle

MATERIAL PROPERTIES		Test Method
Melt temperature	Not applicable	ASTM D3418
Glass transition temperature	~ 105 °C	ASTM D3418
Melt Flow Rate[1]	43.1 g/10min	ISO 1133
Melt Volume Rate[1]	45.9 cm3/10min	ISO 1133
Density	1.04 g/cm3	ASTM D1505
Odor	Little odor	/
Solubility	Insoluble in water	/

[1]Test conditions: T = 210 °C; m = 2.16 kg

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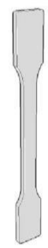
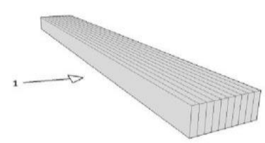
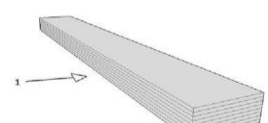
MECHANICAL PROPERTIES | TENSILE TEST			Test Method	ISO 527
All test specimens were printed using an Ultimaker 2+ under the following conditions: Printing temperature: 210 °C Heated bed temperature: 60 °C Print speed: 40 mm/s Number of shells: 2 Infill under 45°	 Printed vertical (Z-axis)		 Printed horizontal (X,Y-axis)	
Infill	50%	100%	50%	100%
Tensile strength (MPa)	4.4 ± 0.6	6.5 ± 1.8	17.0 ± 0.8	29.3 ± 0.8
Force at break (MPa)	2.7 ± 1.8	7.8 ± 1.3	13.6 ± 0.8	26.4 ± 1.8
Elongation at max force (%)	0.5 ± 0.1	0.7 ± 0.1	2.3 ± 0.1	2.4 ± 0.1
Elongation at break (%)	0.5 ± 0.2	0.7 ± 0.1	4.8 ± 0.9	3.7 ± 0.9
Relative tensile strength (MPa/g)	0.7 ± 0.1	0.8 ± 0.2	2.5 ± 0.1	3.0 ± 0.1
Emodulus (MPa)	1031 ± 53	1358 ± 139	1072 ± 38	2030 ± 45

MECHANICAL PROPERTIES | IMPACT TEST		Test Method ISO 179
All test specimens were printed using an Ultimaker 2+ under the following conditions: Printing temperature: 210 °C Heated bed temperature: 60 °C Print speed: 40 mm/s Number of shells: 2 Infill under 45° 1→: impact direction	 Charpy (en)	 Charpy (ep)
Infill	100%	100%
Impact strength (kJ/m^2)	39.3 ± 3.3	35.4 ± 3.4
Impact energy (mJ)	1500.0 ± 134.4	1371.6 ± 125.9

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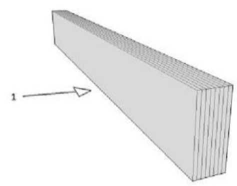
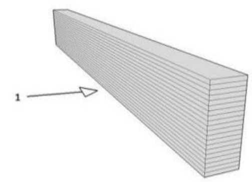
MECHANICAL PROPERTIES | FLEXURAL TEST		Test Method ISO 178
All test specimens were printed using an Ultimaker 2+ under the following conditions: printing temperature: 210 °C heated bed temperature: 60 °C print speed: 40 mm/s number of shells: 2 Infill under 45° 1→: bending direction	 Normal	 Parallel
Infill	100%	100%
Flexural modulus (MPa)	1965.3 ± 115.5	1680.8 ± 127.9
Maximum force (MPa)	67.3 ± 2.3	72.6 ± 1.0
Deformation (%)	4.3 ± 0.1	4.4 ± 0.1

FILAMENT SPECIFICATIONS		Test Method
Diameter 1.75	1.75 ± 0.05 mm	Innofil3D
Diameter 2.85	2.85 ± 0.10 mm	Innofil3D
Max. roundness deviation 1.75	0.05 mm	Innofil3D
Max. roundness deviation 2.85	0.10 mm	Innofil3D
Net weight on reel	750 g ± 2%	Innofil3D

LIST OF COLORS AND CERTIFICATIONS*						
			Certifications/approvals			
Colour	Code	RAL nr.	10/2011 [1]	FDA [2]	2011/65 [3]	EN 71-3 [4]
Naturel	0001	N/A	Yes	Yes	Yes	Yes
Black	0002	9005	Yes	Yes	Yes	Yes
Red	0004	3020	Yes	<u>No</u>	Yes	Yes
Blue	0005	5002	Yes	Yes	Yes	Yes
Yellow	0006	1003	Yes	Yes	Yes	Yes
Green	0007	6018	Yes	Yes	Yes	Yes
Orange	0009	2008	Yes	<u>No</u>	Yes	Yes
Pink	0020	N/A	Yes	<u>No</u>	Yes	Yes
Silver	0021	9006	Yes	Yes	Yes	Yes

* This overview is generated using information obtained from the raw material suppliers.

Certifications/approvals	Description
[1] Regulation EU No 10/2011:	Union Guidelines on Regulation (EU) No 10/2011 on plastic materials and articles intended to come into contact with food (Europe)
[2] FDA:	Food and Drug administration approval (U.S.A.)
[3] Directive 2011/65/EU:	The restriction of the use of certain hazardous substances in electrical and electronic equipment (Europe)
[4] Directive 2009/48/EC; EN 71-3:	Safety of toys – Part 3: Migration of certain elements (Europe)

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Preparation date: 10-07-2017 Version No.: 3.0

Technical Data Sheet

PLA by Innofil3D BV

Filament suitable for all commercially available leading brands 3D FDM/FFF printers

IDENTIFICATION OF THE MATERIAL	
Trade name	Innofil3D PLA
Chemical name	Polylactic Acid
Chemical family	Thermoplastic Polylactic Acid
Use	3D-Printing
Origin	Innofil3D BV

GUIDELINE FOR PRINT SETTINGS	
Nozzle temperature	220 ± 10 °C
Bed temperature	Approx. 60 °C
Bed modification	Tape or glue below 60 °C
Active cooling fan	YES (up to 100%)
Layer height	0.08 – 0.2 mm
Shell thickness	0.4 – 0.8 mm
Print speed	40 – 80 mm/s

Settings are based on a 0.4 mm nozzle

MATERIAL PROPERTIES		Test Method
Melt temperature	145 – 160 °C	ASTM D3418
Glass transition temperature	~ 60 °C	ASTM D3418
Melt Flow Rate[1]	6.09 g/10min	ISO 1133
Melt Volume Rate[1]	6.73 cm3/10min	ISO 1133
Density	1.26 g/cm3	ASTM D1505
Odor	Odorless	/
Solubility	Insoluble in water	/

[1]Test conditions: T = 210 °C; m = 2.16 kg

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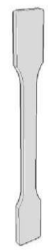
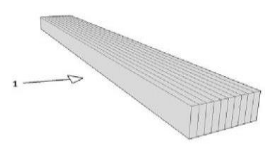
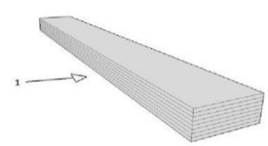
MECHANICAL PROPERTIES | TENSILE TEST Test Method ISO 527

All test specimens were printed using an Ultimaker 2+ under the following conditions: Printing temperature: 210 °C Heated bed temperature: 60 °C Print speed: 40 mm/s Number of shells: 2 Infill under 45°	 Printed vertical (Z-axis)		 Printed horizontal (X,Y-axis)	
Infill	50%	100%	50%	100%
Tensile strength (MPa)	13.6 ± 2.6	28.8 ± 4.2	24.1 ± 0.6	38.1 ± 0.9
Force at break (MPa)	13.4 ± 2.5	28.6 ± 4.1	23.9 ± 0.7	36.3 ± 1.2
Elongation at max force (%)	0.7 ± 0.2	1.1 ± 0.3	2.2 ± 0.1	2.1 ± 0.0
Elongation at break (%)	0.7 ± 0.2	1.1 ± 0.3	2.4 ± 0.1	2.8 ± 0.2
Relative tensile strength (MPa/g)	1.5 ± 0.3	2.4 ± 0.4	2.7 ± 0.1	3.3 ± 0.1
Emodulus (MPa)	2028 ± 59	3150 ± 54	1760 ± 38	2852 ± 88

MECHANICAL PROPERTIES | IMPACT TEST Test Method ISO 179

All test specimens were printed using an Ultimaker 2+ under the following conditions: Printing temperature: 210 °C Heated bed temperature: 60 °C Print speed: 40 mm/s Number of shells: 2 Infill under 45° 1→: impact direction	 Charpy (en)	 Charpy (ep)
Infill	100%	100%
Impact strength (kJ/m^2)	14.2 ± 0.7	13.1 ± 0.7
Impact energy (mJ)	521.5 ± 26.8	501.7 ± 31.1

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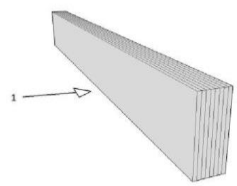
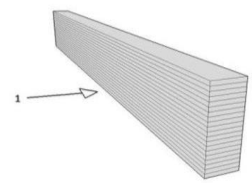
MECHANICAL PROPERTIES | FLEXURAL TEST		Test Method ISO 178
All test specimens were printed using an Ultimaker 2+ under the following conditions: printing temperature: 210 °C heated bed temperature: 60 °C print speed: 40 mm/s number of shells: 2 Infill under 45° 1→: bending direction	 Normal	 Parallel
Infill	100%	100%
Flexural modulus (MPa)	2409.5 ± 206.3	2551.4 ± 100.8
Maximum force (MPa)	65.7 ± 5.3	86.2 ± 3.2
Deformation (%)	4.1 ± 0.2	3.8 ± 0.2

FILAMENT SPECIFICATIONS		Test Method
Diameter 1.75	1.75 ± 0.05 mm	Innofil3D
Diameter 2.85	2.85 ± 0.10 mm	Innofil3D
Max. roundness deviation 1.75	0.05 mm	Innofil3D
Max. roundness deviation 2.85	0.10 mm	Innofil3D
Net weight on reel	750 g ± 2%	Innofil3D

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LIST OF COLORS AND CERTIFICATIONS*						
			Certifications/approvals			
Colour	Code	RAL nr./ Pantone	10/2011[1]	FDA[2]	2011/65[3]	EN 71-3[4]
Naturel	0001	N/A	Yes	Yes	Yes	Yes
Black	0002	9005	Yes	Yes	Yes	Yes
White	0003	9010	Yes	Yes	Yes	Yes
Red	0004	3020	Yes	No	Yes	Yes
Blue	0005	5002	Yes	Yes	Yes	Yes
Yellow	0006	1003	Yes	Yes	Yes	Yes
Green	0007	6018	Yes	Yes	Yes	Yes
Army Green	0009	6003	Yes	Yes	Yes	Yes
Orange	0009	2008	Yes	No	Yes	Yes
Pearl White	0011	1013	Yes	Yes	Yes	Yes
Chocolate Brown	0013	8017	Yes	Yes	Yes	Yes
Gold	0014	1036	Yes	Yes	Yes	Yes
Light Blue	0015	5012	Yes	Yes	Yes	Yes
Violet	0016	4008	Yes	Yes	Yes	Yes
Apricot Skin	0019	7415C	Yes	No	Yes	Yes
Pink	0020	N/A	Yes	No	Yes	Yes
Silver	0021	9006	Yes	Yes	Yes	Yes
Magenta	0022	4010	Yes	No	Yes	Yes
Grey	0023	7045	Yes	No	Yes	Yes
Bronze	0032	8008	Yes	Yes	Yes	Yes
Sky Blue	0035	N/A	Yes	Yes	Yes	Yes
Orange Translucent	0010	1028**	Yes	Yes	Yes	Yes
Blue Translucent	0024	5022**	Yes	Yes	Yes	Yes
Dark Green Translucent	0025	6005**	Yes	Yes	Yes	Yes
Ice Blue Translucent	0026	5024**	Yes	Yes	Yes	Yes
Ocean Blue Translucent	0027	5001**	Yes	Yes	Yes	Yes

* This overview is generated using information obtained from the raw material suppliers.
** RAL number used to manufacture the (semi-)transparent colour.

Certifications/approvals	Description
[1] Regulation EU No 10/2011:	Union Guidelines on Regulation (EU) No 10/2011 on plastic materials and articles intended to come into contact with food (Europe)
[2] FDA:	Food and Drug administration approval (U.S.A.)
[3] Directive 2011/65/EU:	The restriction of the use of certain hazardous substances in electrical and electronic equipment (Europe)
[4] Directive 2009/48/EC; EN 71-3:	Safety of toys - Part 3: Migration of certain elements (Europe)

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NinjaTek **Technical Specifications**

NinjaFlex® 3D Printing Filament

Flexible Polyurethane Material for FDM Printers

NinjaFlex flexible filament leads the industry with superior flexibility and longevity compared to non-polyurethane materials. Its consistency in diameter and ovality (roundness) outpaces other polyurethane materials. Made from a specially formulated thermoplastic polyurethane (TPU) material, this patented technology contains a low-tack, easy-to-feed texture. The result is uniquely flexible, strong prints ideal for direct-drive extruders.

General Properties	Test Method	Imperial	Metric
Specific Gravity	ASTM D792	1.19 g/cc	1.19 g/cc
Moisture Absorption - 24 hours	ASTM D570	0.22 %	0.22 %

Mechanical Properties			
Tensile Strength, Yield	ASTM D638	580 psi	4 Mpa
Tensile Strength, Ultimate	ASTM D638	3,700 psi	26 Mpa
Tensile Modulus	ASTM D638	1,800 psi	12 Mpa
Elongation at Yield	ASTM D638	65%	65%
Elongation at Break	ASTM D638	660%	660%
Toughness (integrated stress-strain curve; calculated stress x strain)	ASTM D638	12,000 in·lbF/in^3	82.7 m*N/m^3 x10^6
Hardness	ASTM D2240	85 Shore A	85 Shore A
Impact Strength (notched Izod, 23C)	ASTM D256	2.0 ft.lbf/in^2	4.2 kJ/m^2
Abrasion Resistance (mass loss, 10,000 cycles)	ASTM D4060	0.08 g	0.08 g

Thermal Properties			
Melting Point (via Differential Scanning Calorimeter)	DSC	420° F	216° C
Glass Transition (Tg)	DSC	-31° F	-35° C
Heat Deflection Temperature (HDT) @ 10.75psi/ 0.07 MPa	ASTM D648	140° F	60° C
Heat Deflection Temperature (HDT) @ 66psi/ 0.45 MPa	ASTM D648	111° F	44° C

NinjaTek filament is capable of being printed by a variety of printers in a variety of configurations. This specification sheet gives results as they pertain to the defined test standard and specimen details. Different slicing and/or printing configurations, test conditions, ambient environments, etc. may result in different results.

Impact Strength and Heat Deflection Temperature results were both provided by an accredited university testing laboratory. Specific Gravity and Hardness are innate characteristics of the material. Moisture Absorption, values associated with the Tensile Strength tests, Melting Point and Glass Transition data were prepared by Fenner Drives, Inc.

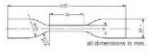
NinjaTek makes no warranties of any type, express or implied, including, but no lited to, the warranties of fitness for a partuclar application.

Test Specimen Details (by ASTM Test Number)
All printed specimens were created using the TAZ5 printer 0.75mm nozzle. For ASTM D638 tests, the extrusion multiplier is 1.05.

Specific Gravity (D792): Results determined by nature of material.

Moisture (D570): 30g of filament tested in moisture analyzer evaluated at 125°C until the mass change is < 0.005% over 1 minute.

Tensile (D638): Dogbone Style IV, 100% fill, diagonal line fill. Dimensions: 5mm thick. See drawing for other dimensions.



Hardness (D2240): Solid testing block.

Dimensions: 2"L x 2" H x 0.75" W

Impact (D256): Un-notched test specimen, notch added post print by testing facility.

Dimensions: 2.5 " L x 0.25" H x 0.5" W

Abrasion (D4060): Rectanglar block sized to fit tabor abrader.

Dimensions: 5" L x 0.5" H x 0.5" W

HDT (D648): Bar shape.

Dimensions: 7.5" L x 0.125" H x 0.5" W

PRO Series Nylon Physical Properties Datasheet

Property	Test Method	Value	Comment
Melt Flow Index/ g/10 mins	ASTM D1238	5 – 15	Dependent on color. Tested at < 400 ppm moisture
Density/ gcm^{-3}	ASTM D792	1.14	Resin Manufacturer data
Heat Deflection Temperature/ °C *	ASTM D648 at 66 psi	110	
Flexural Peak Stress/ psi *	ASTM D790	6403	
Flexural Modulus/ kpsi *	ASTM D790	152	
Tensile Strength at Break/ psi *	ASTM D638, Type IV	6072	
Tensile Strength at Yield/ psi *	ASTM D638, Type IV	7582	
Tensile Elongation/ % *	ASTM D638, Type IV	27	
Tensile Modulus/ kpsi *	ASTM D638, Type IV	200	
Notched Izod Impact/ Jm^{-1} *	ASTM D256	360	

* 3D printed test specimens, 100 % solid, y-axis orientation